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Title:

WINDSHIELD AND SOUND-BARRIER FOR SEISMIC SENSORS

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WINDSHIELD AND SOUND-BARRIER FOR SEISMIC SENSORS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119(e) to United States Provisional Application No. 60/427,671, titled "Windshield and Sound-Barrier for Seismic Sensors," filed November 19, 2002, the entirety of which is hereby incorporated by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was made by an agency of the United States Government, or under contract with an agency of the United States Government. The name of the United States Government agency and the government contract number are: DARPA/SPO, Contract Number F33615-02-C-1262.

BACKGROUND OF THE INVENTION

[0003] Field of the Invention. This invention relates generally to improved geophones and other motion or seismic sensors. More specifically, this invention relates to a system for reducing wind noise and other background noise that may interfere with signals sensed by a geophone or other ground motion or seismic sensor.

[0004] Related Art. Noise can be a significant problem for the acquisition of high-quality seismic data. In general, there are two types of noise that are of particular concern. First is noise created by winds that blow against seismic sensors, such as geophones. Strong winds can interrupt seismic survey operations or decrease the detection range of sensors by reducing signal-to-noise ratios below acceptable limits. Second is acoustic noise. Seismic sensors such as geophones are also sensitive to ground motion induced by acoustic signals. Acoustic noise

levels, therefore, also influence the signal-to-noise ratios recorded by such sensors, potentially limiting their detection capability.

[0005] One common practice for reducing the effect of wind and acoustic noise is to bury the sensor. However, burial of sensors is time consuming, and thereby costly. Also, local ground conditions may preclude the burying of sensors to depths which sufficiently reduce noise.

[0006] Thus, a need exists for an improved system and method for reducing the effects of wind and/or acoustic noise on geophones and similar sensors, which does not require the burial of such sensors.

SUMMARY OF THE INVENTION

[0007] The present invention provides a system and method for reducing acoustic, wind or other background noise that may interfere with a seismic sensor, such as a geophone. In one embodiment, a shield is provided to enclose the geophone and thereby protect it from harmful noise. This shield may comprise a substantially rigid shell, a structural damping material layer coupled to the shell, an acoustically absorptive material layer coupled to the structural damping material layer, and a compliant seal coupled to the ground or other reference surface. The shield, however, need not have all of the above-described elements, so long as the shield is configured to provide an acoustic transmission loss, a wind noise loss, or both. Thus, for example, the shield may comprise only the rigid shell. The shield may alternatively comprises only the shell coupled to a mass layer. The shield may alternatively comprise the shell, the mass layer, a structural damping material layer and/or an acoustically absorptive material layer. In the above-described embodiments, the shield should generally not interfere with the functioning of the sensor, such as by physically contacting the sensor.

[0008] In another embodiment, the shield and the seismic sensor may be provided as an integral unit. Thus, the shield and the sensor may be coupled by means of a suspension. In such an embodiment, the suspension may be designed in such a way that the shield may act as a bias

mass to improve the coupling between the seismic sensor and the reference surface, without interfering with the measurements of the sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1A depicts a cross-sectional side view of a shield according to an embodiment of the present invention.

[0010] FIG. 1B depicts a top view of the shield of FIG. 1A.

[0011] FIG. 2 depicts a cross-sectional side view of a shield according to another embodiment of the present invention.

[0012] FIG. 3 depicts a cross-sectional side view of a shield according to another embodiment of the present invention.

[0013] FIG. 4A depicts a cross-sectional side view of a shield according to another embodiment of the present invention.

[0014] FIG. 4B depicts a cross-sectional side view of a shield according to another embodiment of the present invention.

[0015] FIG. 5 depicts the results of comparison test between a geophone enclosed by a shield according to an embodiment of the present invention and an unshielded geophone.

[0016] FIG. 6 depicts a cross-sectional side view of a shield according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] Reference will now be made to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings.

[0018] In embodiments of the present invention, a shield is provided that encloses a geophone or other sensor, thereby protecting it from direct exposure to the wind. Preferably, the shield is constructed so as also to provide a large acoustic transmission loss, thereby shielding the geophone or other sensor from sound energy associated with the wind or ambient acoustic levels.

In general, it is desirable to reduce the wind and acoustic noise levels as much as possible, given a set of geometric and cost constraints in a given application.

[0019] An embodiment of the present invention can be seen in FIGs. 1A-B. FIG. 1A shows a side-view cross-section of an embodiment of the present invention. A shield **101** is provided such that it encloses geophone **102**, which is coupled to reference surface **103**. As would be understood by one skilled in the art, a geophone is a sensor that is used to detect ground motion. Geophones are often used to detect earthquakes and machine vibrations, as well as in oil exploration and mining. In general, geophones comprise a metal case with a mass suspended on a spring between a series of magnets. Usually, they are coupled to the reference surface by means of a spike, such as spike **108**, as shown in FIG. 1A. As the reference surface moves, a relative motion is induced between the metal case and the suspended internal mass. This relative motion, in the presence of the magnetic field caused by the magnets, induces small currents in electric coils that are attached to the suspended internal mass. These currents are proportional to the velocity of the reference surface and can be used to determine the velocity of the motion of the reference surface. Moreover, while the present invention is preferably used with a geophone, it could also be used with a variety of sensors in situations where reducing vibration from wind and acoustic noise is desirable. For example, the present invention could be used with an accelerometer, which measures the acceleration of the reference surface rather than velocity.

[0020] In one embodiment, shield **101** is approximately 2 feet in diameter and is generally dome-shaped, that is, when looked at from a top view, as in FIG. 1B, it has a generally circular cross-section. However, as should be understood by one skilled in the art, the present invention is not limited to such a shape, and other suitable shapes are within the scope of this invention.

[0021] In this embodiment, shield **101** is simply a rigid shell, made from a material such as a metal or fiberglass. In some embodiments, the rigid shall may comprise a lead sheet or lead vinyl layer with a mass of at least 1 lb. per square foot and preferably 2 lbs. per square foot. This rigid shell protects the geophone **102** from noise such as wind noise.

[0022] Compliant seal **107** couples shield **101** to the reference surface **103**. Preferably, compliant seal **107** may be made from an air filled rubber tube. Alternatively, compliant seal **107** may be made from a sand filled rubber tube, such that the weight of sand effectively seals

the shield **101** and prevents acoustic energy or wind from reaching the geophone. In general, the compliant seal should substantially eliminate gaps that may provide acoustic flanking paths. Thus, compliant seal **107** may be made from a wide variety of materials, so long as it substantially prevents acoustic energy or wind from going under shield **101**.

[0023] A cross-sectional side-view of an alternative embodiment is shown in FIG. 2. In the embodiment in FIG. 2, a shield **201** is provided to enclose geophone **202**, which is coupled to reference surface **203**. Shield **201** comprises a mass layer **204** which surrounds a rigid shell **205**. The mass layer **204** is preferably made from a lead vinyl layer with a mass of at least 1 lb. per square foot, and preferably 2 lbs. per square foot. Rigid shell **205**, preferably made from a metal or fiberglass, prevents the mass layer **204** from contacting the geophone **202**. Alternatively, the positions of rigid shell **205** and mass layer **204** could be reversed, so long as neither layer touches the enclosed geophone **202**.

[0024] A cross-sectional side-view of still another alternative embodiment is shown in FIG. 3. Once again, shield **301** is provided to enclose geophone **302**, which is coupled to reference surface 303. Shield **301** comprises a rigid shell **304** coupled to a structural damping material layer **305** to prevent the build-up of vibration energy in the shell. In preferred embodiments, structural damping material layer **305** is made from an elastomeric material, such as a rubber or plastic material, or any other material that provides visco-elastic damping. Damping may also be provided by constrained layer damping. Seal **307**, similar to seal **107** (FIG. 1A), may also be provided.

[0025] A cross-sectional side-view of still another alternative embodiment is shown in FIG. 4A. Once again, shield **401** is provided to enclose geophone **402**, which is coupled to reference surface **403**. Shield **401** comprises a rigid shell **404** coupled to a structural damping material layer **405** to prevent the build-up of vibration energy in the shell (similar to structural damping material layer **305** (FIG. 3)). Shell **404** is preferably substantially rigid, and formed into an aerodynamic shape such that structural excitation from local flow separation and turbulence is minimized. Preferred materials for shell **404** include metal or fiberglass. For example, shell **404** may comprise a lead sheet or a lead vinyl blanket which surrounds a rigid piece of plastic or the like in order to maintain the shape of shell **404**. In the embodiment shown in FIG. 4A, shell **404**

also functions as a "mass layer," in that the shell itself has a significant mass, so there is no need to provide a separate mass layer. A mass layer, whether provided as the shell or separately, preferably provides an acoustic transmission loss, a wind noise loss, or both. For example, if a shell **404** has a mass of at least 1 pound per square foot (and preferably about 2 pounds per square foot), it may provide the necessary amount of acoustic transmission loss, wind noise loss, or both in a given application.

[0026] Alternatively, if additional mass is needed, a mass layer may be provided separately from the shell. For example, in the embodiment shown in FIG. 4B, shield **450** is provided with a shell **451** and a mass layer **452**, which is coupled to the shell **451**, provided separately. The mass layer **452** may comprise a lead vinyl blanket. In addition, in the embodiment shown in FIG. 4B, structural damping material layer **453** is provided coupled to the mass layer **452** and acoustically absorptive material layer **454** is provided coupled to the structural damping material layer **453**. Characteristics of structural damping material layers and acoustically absorptive material layers are discussed in more detail below with respect to FIG. 4A. Moreover, mass layers of different weight per area may be used to provide various acoustic transmission or wind noise losses as required by the particular application. For example, a mass layer of at least 1 pound per square foot (and preferably about 2 pounds per square foot) may be used in particular applications.

[0027] Turning back to the embodiment shown in FIG. 4A, immediately adjacent to shell **404** is structural damping material layer **405**. Structural damping material layer **405** is preferably coupled to the shell **404** to prevent the build-up of vibration energy in the shell, and is similar to structural damping material layer **305** (FIG. 3).

[0028] Immediately adjacent to structural damping material layer **405** is acoustically absorptive material layer **406**. Acoustically absorptive material layer **406** reduces resonant acoustic modes within the volume enclosed by shield **401**. Preferably, acoustically absorptive material layer **406** is made from an open cell foam material, and can be made from fiberglass. In a preferred embodiment, acoustically absorptive material layer **406** is the thickest of the layers of shield **401**, and may be approximately 1 inch thick, although this may vary widely from application to application. A preferred overall thickness for shield **401** (including shell **404**, structural damping

material layer **405**, and acoustically absorptive material layer **406**) is approximately 2 inches, although again, this could vary widely from application to application.

[0029] Finally, a compliant seal **407** couples shield **401** to the reference surface **403**. This is similar to seal **107** (FIG. 1A).

[0030] In general, while representative dimensions and specific material compositions of the various shields were described above, these are not critical to the invention. Rather, a variety of dimensions and materials can be employed depending on the performance bandwidth that is relevant in a given application and the amount of attenuation required. Nevertheless, it is preferable that while the shield encloses the geophone, it also provides sufficient airspace to prevent contact during the course of usual use of the sensor. Moreover, not all of the layers described above need be provided in a specific application.

[0031] Tests have been conducted showing the effectiveness of the present invention. A shield built generally according the embodiment described in FIGs. 1A-B was tested on a day in which wind speeds were generally between 10 and 20 miles per hour, and overall geophone noise levels were observed to correlate with wind velocities. Wind noise levels were measured for a standard OYO Geospace GS-32CT geophone placed underneath a simplified shield made according to the embodiment described in FIGs. 1A-B. Thus, the shield used in the test consisted of a shell made of a lead sheet with a mass of 1lb. per square foot, and 2 feet in diameter. Measurements were taken of the reduction of wind noise levels of the shielded geophone versus that of an unshielded reference geophone placed nearby. The results are shown in FIG. 5.

[0032] As can be seen from FIG. 5, a significant wind noise reduction is observed, which increases as frequency increases. For example, at 200 Hz, a 10 dB reduction of wind noise was observed, and at 100 Hz, a 5 dB reduction of wind noise was observed. These noise reduction levels are similar to the noise reduction levels achieved by geophone burial, the current common method of reducing noise. Further reductions of noise can be expected by applying the embodiment described with respect to FIG. 4A. In particular, in addition to wind noise reductions, significant acoustic noise reductions could be obtained as well.

[0033] A cross-sectional side-view of another embodiment of the present invention is shown in FIG. 6. In this embodiment, shield **601** and geophone **602** are provided as an integral unit. In such an embodiment, shield **601** could provide a bias mass to geophone **602**, in order to improve the coupling of geophone **602** to reference surface **604**. For a more detailed discussion of improved geophone coupling, see commonly owned United States Provisional Applications 60/427,426 and 60/427,425, filed November 19, 2002, entitled "Ground Sensor with Improved Seismic Coupling," and "Method and System for Evaluating Geophone Coupling" respectively, and their respective co-pending non-provisional applications of the same name, filed simultaneously herewith, the entirety of all of which are hereby incorporated herein by reference.

[0034] Shield **601** may be provided as described above with respect to FIGs. 1A-B, 2, 3, 4A-B, or in any other arrangement that provides the necessary wind and/or acoustic screening for a given application. Shield **601** and geophone **602** are coupled by means of suspension **603**. In a preferred embodiment, suspension **603** is designed so that the mass of shield **601** does not substantially influence the measurements of geophone **602**. Thus, suspension **603** may comprise rigid connectors **605** and **606**, and spring/damper systems **607** and **608**. Suspension designs are further discussed in the above mentioned Provisional Patent Application 60/427,426.

[0035] Finally, the present invention could be used with the invention described in the patent application entitled "Improved Geophone," inventor James E. Barger, having assignee in common with assignee of this instant application, bearing internal docketing number 02-4098, and filed on even date herewith, the entirety of which is hereby incorporated herein by reference.

[0036] Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art and consequently it is intended that the claims be interpreted to cover such modifications and equivalents.